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FIELD-EMITTER ARRAYS FOR RF VACUUM MICROELECTRONICS

C.A. Spindt, Program Director
A. Rosengreen, Senior Research Engineer
P.R. Schwoebel, Research Engineer
Physical Electronics Laboratory

SRI Project 2743

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Advanced Research Projects Agency
Defense Sciences Office
Virginia Square Plaza
3701 North Fairfax Drive
Arlington, VA 22203-1714

Attn: Dr. Bertram H. Hui

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333 Ravenswood Avenue • Menlo Park, CA 94025-3493 • (415) 326-6200 • FAX (415) 326-5512 • Telex 334486

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C.A. Spindt, A. Rosengreen, and P.R. Schwoebel

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SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025-3493

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SRI International has completed the sixth quarter of a program to develop field-emitter arrays for vacuum microelectronics. We have met the first-phase program goals of 5 mA total emission, with a current density of 5 A/cm^2 for at least 2 hours and demonstrated modulation of the emission current at a frequency of 1 GHz.

A series of controlled tests was initiated with photoresist/developer/stripper combinations to identify the source of a contamination problem in the low-capacitance cathode fabrication technology.

A sequence of procedures was specified for cathode emission tests, using previously developed test chambers.

High-frequency testing with a triode setup at 1-GHz modulation rates was begun.

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EXECUTIVE SUMMARY

SRI International has completed the sixth quarter of Phase I of a research and development program on the SRI Spindt-type field-emitter-array cathode with a view toward eventual applications in microwave amplifiers. We have met the first-phase goals of 5 mA total emission, with a current density of 5 A/cm^2 for at least 2 hours and demonstrated modulation of the emission current at a frequency of 1 GHz. Our approach has been to identify methods of adapting and modifying the basic cathode structure of microwave operation and to experimentally investigate means of implementing those methods.

During the quarter we have accomplished the following, as documented in detail in this technical report:

- Continued research on basic cathode technology as defined by the goals of the ARPA program and related NRL project (Section 1)
- Begun a series of controlled tests with photoresist/develop/stripper combinations to identify the source of a contamination problem in the low-capacitance cathode fabrication technology (Section 2)
- Specified a sequence of procedures for cathode emission tests, using our previously developed test chambers (Section 3)
- Begun high-frequency testing with a triode setup at 1-GHz modulation rates (Section 4)
- Planned activities for the period of 1 April through 30 June 1993 (Section 5)

CONTENTS

1. INTRODUCTION

SRI International is participating in an effort of the Advanced Research Projects Agency (ARPA) and the Naval Research Laboratory (NRL) to perform research and development on the SRI Spindt-type field-emitter-array cathode with a view toward eventual applications in microwave amplifiers. The current ARPA program is the vehicle for advancing the basic cathode technology for microwave applications (e.g., reducing intrinsic capacitance and driving voltage requirements), and continues the original program plan to establish the characteristics of the cathode in its preprogram state of development, identify methods of adapting and modifying the structure for microwave operation, and experimentally investigate means of implementing those methods. For the NRL program, which began earlier than the ARPA project, SRI has shifted emphasis to the support of NRL's in-house vacuum microelectronics program by providing NRL with state-of-the-art Spindt-type cathodes and consultation on setting up and using cathodes. We have met the first-phase program goals of 5 mA total emission, with a current density of 5 A/cm^2 for at least 2 hours and demonstrated modulation of the emission current at a frequency of 1 GHz.

At the beginning of the program, two areas of development required immediate attention. The first was a materials and processing issue related to providing and maintaining a suitable vacuum environment for the cathodes. The second related to the cathode's inherent high capacitance and means for reducing that capacitance to a level that is consistent with the microwave applications envisioned for the cathode.

Our approach has been to research these two issues in parallel, using an easy-to-build, low-frequency-triode configuration fabricated on a TO-5 header as a test vehicle for materials and processing studies, and at the same time designing and researching fabrication techniques for building high-frequency-cathode structures on dielectric substrates (e.g., quartz or glass). Specific tasks that are being addressed on these related programs are:

1. Fabrication of a supply of state-of-the-art cathodes for use in establishing cathode characteristics, and for developing structures, circuits, and procedures for testing the cathodes as triodes
2. Development of a close-spaced anode test configuration that can be used to investigate triode characteristics at low frequency (kHz to MHz) in order to study the known problems with cathode survival under close-spaced anode conditions
3. Development of a circuit for driving the cathodes and demonstrating gain, frequency response, and peak emission levels
4. Studies of advanced cathode structures (geometry, fabrication technology, and processing) for high-frequency operation

5. Investigations (with NRL) of cathode mounting and connecting procedures using practices that are consistent with the microwave goals of the effort

6. Consultations with the NRL staff on the experimental results and applications of the cathode technology

2. LOW-CAPACITANCE CATHODE FABRICATION

Efforts to eliminate or remove residue from the new photoresists continued. As reported during the previous quarter, we determined that sputter cleaning of the base film after patterning was effective in removing residue from the base. However, sputtering of the gate was not successful because of contamination of the silicon dioxide sidewalls of the holes. This quarter, we continued cathode fabrication, using subtle variations in processing, such as milder temperatures in the hard-bake cycle of the photoresist, so as to facilitate subsequent stripping. In addition, we found that the ovens used to bake our photoresists were not reliable with regard to maintaining set temperatures, and we felt that this could have contributed to the contamination problem.

We constructed a hot plate designed to bake photoresists at a reliable and repeatable temperature. Bakeout was superior to that of the previously used ovens. However, this did not eliminate the contamination problem that had been plaguing the fabrication efforts since the photoresist materials were changed.

In one experiment, we noted that after the removal of the photoresist with stripper and hot phosphoric acid—which usually brightens the molybdenum—the molybdenum gate film was slightly discolored (brownish) where the photoresist for the cathode hole etch had been. We also observed that a corner of the substrate, from which the photoresist had been removed by scraping in order to make electrical contact to the gate film for electropolish etching of the holes, was not discolored.

An attempt to remove the discoloration by reactive ion etching in O_2 and CF_4 was successful. However, subsequent cleaning in hot phosphoric acid resulted in the reappearance of the discoloration everywhere but in the corner that had been scraped clean. The molybdenum was not scratched or burnished by the scraping of the resist, because the resist lifted off under the scraping action used to remove it.

During February, we began a series of controlled tests with glass and silicon substrates and a matrix of photoresist/developer/stripper combinations in an attempt to identify the source of the problem. Five results have emerged to date:

1. Only the 1375 photoresist has produced contamination in the tests.

2. Once the discoloration has appeared, nothing but sputtering has been able to remove it.

3. All attempts to remove the discoloration with chemicals have made it worse.

4. There appears to be no difference in results with the R-10 stripper and the 2001 stripper.

5. The results of these controlled tests have not always been consistent with the observations made during actual cathode processing.

Our efforts to identify the source of the contamination will continue with Auger spectrometer analysis of the contaminated surfaces.

3. EMISSION TESTS

The testing vessels for low-capacitance, high-frequency cathodes were completed and put on line early in the quarter. These vessels were described in detail in earlier reports. Each of the two high-frequency test chambers has test sites for four cathodes.

A low-frequency qualifying chamber with test sites for six cathodes mounted in the stripline fixtures designed for microwave testing was also assembled and brought on line. We plan to qualify the cathodes in the relatively low-frequency qualifying chamber, and then transfer the best four of the six qualified cathodes into one of the high-frequency chambers. We estimate that, on the average, at least two out of three cathodes would be acceptable.

While the high-frequency chamber is undergoing vacuum processing, a second batch of six cathodes can be qualified in the qualifying chamber. Following this, the second high-frequency chamber will be loaded with qualified cathodes and vacuum processed while the first high-frequency chamber is undergoing high-frequency testing and the low-frequency chamber is cycled again to qualify a new batch of cathodes for the first high-frequency chamber.

This sequence will be continued while improved processing and modified structures evolve from parallel fabrication and design efforts, and as experience is gained and processing and measurement techniques are improved. We expect to interact closely with NRL on interpreting and evaluating the results of these tests.

In late January, we could not successfully test cathodes fabricated using the new photoresists and strippers. The cathodes were erratic, relatively high voltage, and tended to fail to short circuits between the base and gate at an early age. For these reasons, no new cathodes were tested during the remainder of the quarter.

4. HIGH-FREQUENCY TESTS

Using our high-frequency test vehicles, we were able to make measurements with a triode setup at 1-GHz modulation rates. Difficulties with the Hewlett-Packard 8510 Network Analyzer prevented us from obtaining satisfactory S-parameter measurements. These difficulties appear to have resulted from the calibration standards that had been prepared for this work. New parts have been ordered so that we can continue the tests.

Because of the poor cathode quality, we discontinued high-frequency measurements early in February.

5. WORK PLANNED

Efforts will be directed toward fabrication of a supply of cathodes for testing at NRL and SRI, and characterization of the cathodes with the Hewlett-Packard 8510 Network Analyzer.

We will also continue our work toward solving the photolithography contamination problem.